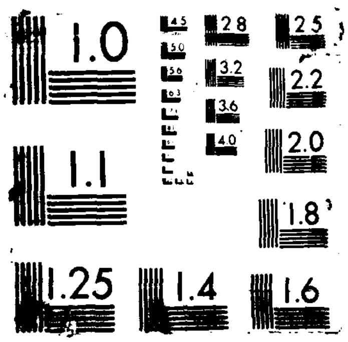
AD-A195 581 HARPOON GRADE B CANISTER VIBRATION DATA STUDY(U) 1/1
NONDESTRUCTIVE TESTING INFORMATION ANALYSIS CENTER SAN
ANTONIO TX D J POMERENING ET AL. 30 AUG 85
UNCLASSIFIED DLA900-79-C-1266 F/G 16/1 NL


1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

(1)



# HARPOON GRADE B CANISTER VIBRATION DATA STUDY

By

Daniel J. Pomerening

Daniel D. Kana



FINAL REPORT

SwRI Project 15-5607-826

Prepared for

United States Navy

Pacific Missile Test Center (PMTC)

Pt. Mugu, California 93042

Performed as a special Task for the Nondestructive Testing Information Analysis Center under Contract Nos. DLA-900-79-C-1266; DLA900-84-C-0910

August 1985



SOUTHWEST RESEARCH INSTITUTE

SAN ANTONIO HOUSTON

SOUTHWEST RESEARCH INSTITUTE
Post Office Drawer 28510, 6220 Culebra Road
San Antonio, Texas 78284

# HARPOON GRADE B CANISTER VIBRATION DATA STUDY





By
Daniel J. Pomerening
Daniel D. Kana

FINAL REPORT
SwRI Project 15-5607-826

Prepared for
United States Navy
Pacific Missile Test Center (PMTC)
Pt. Mugu, California 93042

Performed as a special Task for the Nondestructive
Testing Information Analysis Center under Contract Nos.
DLA-900-79-C-1266; DLA900-84-C-0910

August 1985

Approved:

Thomas A. Cruse, Director
Department of Engineering Mechanics

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

ADA195581

# REPORT DOCUMENTATION PAGE

**1a. REPORT SECURITY CLASSIFICATION:** Unclassified

**1b. RESTRICTIVE MARKINGS:**

**2a. SECURITY CLASSIFICATION AUTHORITY:**

**2b. DECLASSIFICATION / DOWNGRADING SCHEDULE:**

**3. DISTRIBUTION / AVAILABILITY OF REPORT:** Approved for public release; distribution unlimited

**4. PERFORMING ORGANIZATION REPORT NUMBER(S):** 15-5607-826

**5. MONITORING ORGANIZATION REPORT NUMBER(S):**

**6a. NAME OF PERFORMING ORGANIZATION:** NTIAC, Southwest Research Institute

**6b. OFFICE SYMBOL (If applicable):**

**7a. NAME OF MONITORING ORGANIZATION:** Pacific Missile Test Center

**6c. ADDRESS (City, State, and ZIP Code):** P.O. Drawer 28510, San Antonio, TX 78284

**7b. ADDRESS (City, State, and ZIP Code):** Pt. Mugu, CA 93042

**8a. NAME OF FUNDING / SPONSORING ORGANIZATION:** Defense Logistics Agency

**8b. OFFICE SYMBOL (If applicable):** DTIC-DS

**9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER:** DLA900-79-C-1266, CLIN 0001AW

**8c. ADDRESS (City, State, and ZIP Code):** DTIC, Cameron Station, Alexandria, VA 22314

**10. SOURCE OF FUNDING NUMBERS**

| PROGRAM ELEMENT NO. | PROJECT NO. | TASK NO. | WORK UNIT ACCESSION NO. |
|---|---|---|---|
| | | | |

**11. TITLE (Include Security Classification):** HARPOON Grade B Canister Vibration Data Study

**12. PERSONAL AUTHOR(S):** Daniel J. Pomerening, Daniel D. Kana

**13a. TYPE OF REPORT:** Final

**13b. TIME COVERED:** FROM 9/29/83 TO 8/30/85

**14. DATE OF REPORT (Year, Month, Day):** 8/30/85

**15. PAGE COUNT:** 23

**16. SUPPLEMENTARY NOTATION:** Performed as a Special Task for the Nondestructive Testing Information Analysis Center.

**17. COSATI CODES**

| FIELD | GROUP | SUB-GROUP |
|---|---|---|
| | | |
| | | |

**18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number):**
Nondestructive Testing
Missile System Reliability
Failure Data Analysis

**19. ABSTRACT (Continue on reverse if necessary and identify by block number)**


Tests were performed on the HARPOON missile Grade B canister to determine the cause of high failure rate. Shipboard testing was reviewed and recommendations are made for corrective action.


**20. DISTRIBUTION / AVAILABILITY OF ABSTRACT:** ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS

**21. ABSTRACT SECURITY CLASSIFICATION:** Unclassified

**22a. NAME OF RESPONSIBLE INDIVIDUAL:** Gary Ribiat

**22b. TELEPHONE (Include Area Code):**

**22c. OFFICE SYMBOL:**

TABLE OF CONTENTS

# PREFACE

This project was performed by Southwest Research Institute (SwRI) for the Pacific Missile Test Center (PMTC) as a special task under the auspices of the Nondestructive Testing Information Analysis Center (NTIAC). Funding was provided through NTIAC under Contract DLA900-79-C-1266 and DLA900-84-C-0910.

Technical performance for this program was under the direction of Mr. Daniel J. Pomerening and Dr. Daniel D. Kana, while management cognizance was provided by Dr. John Labra, all members of the Engineering and Materials Sciences Division of SwRI. Technical and financial monitors at PMTC included Mr. Gary Ribiat and Mr. Tom Blattel. Coordination through NTIAC was provided by Dr. G. A. Matzkanin, Director of NTIAC.

## 1.0 INTRODUCTION

This document constitutes a final report on Southwest Research Institute's (SwRI) participation in the analysis of data from HARPOON testing performed for the Pacific Missile Test Center (PMTC). This work has been performed under a special task for the Nondestructive Testing Information Analysis Center (NTIAC). The following areas have been approached:

1) Review of Shipboard Testing (CGN-40)
2) Modal Analysis Testing (DD-995)
3) Review of Laboratory Testing at PMTC
4) Recommendations

A review of each of these areas and a relationship between the work performed and the initial scope of work [7.1]* will be discussed.

It is our understanding that the HARPOON canister testing sequence was initiated as the result of a high failure rate of the missiles installed in Grade B canisters. SwRI's participation in the program began with input into the captive carry program on the USS Mississippi (CGN-40) and subsequent analysis of the data produced during this testing [7.2 to 7.4]. Indications were that significant dynamic response of the missile was present during the captive carry program. Due to questions concerning the validity of the data taken during this testing, additional phases of the program were undertaken. One consisted of the performance of a modal analysis of the missile/canister/launch support structure onboard ship [7.5]. From this data, some answers to questions that arose during the captive carry program were obtained. There was significant dynamic response of the system, and this response was dominated, in the low frequency range, by motion of the missile/canister group on the launch support structure.

At the same time, testing was begun at PMTC on a single missile/canister configuration. These tests were designed to further define the dynamic characteristics of the combination and explore several possible modifications designed to reduce the level of energy transmitted to the critical electronic components of the missile. In support of this phase of the program, SwRI participated in the review of the testing being performed at PMTC and the data produced. A large amount of data had to be reviewed to determine the important parameters. In addition to reviewing data supplied by PMTC, SwRI performed some analysis of the data to obtain information required to define the response of the missile in the canister. It was concluded [7.6] that the modifications considered did not significantly alter the dynamic characteristics of the missile.

At the initiation of the program, the cause of the high failure rate of the HARPOON in the Grade B canister had not been defined. Indications were that the majority of the failures had occurred in the electronic components near the nose of the missile. It was not possible to determine from the literature if the failures were specifically the result of the in-service

*Number in brackets refers to references in Section 7.0.

vibration or shock environments. The USS Mississippi testing did show that there was significant dynamic response of the missile/canister/launch support structure excited by normal operating conditions of the ship. It was possible that this dynamic response had some effect on the failure rate of the system. Subsequent modal analysis testing showed that the low-frequency dynamic responses were dominated by motion of the missile/canister group on the flexible launch support structure. Some of the higher-order modes showed flexing of the missile/canister combination. The first approach to reduce the levels of the dynamic response of the electronic components was modification of the interface between the missile and canister. After a series of tests at PMTC which were performed on a single missile/canister set and included several proposed modifications, it was determined that it was possible to shift the primary frequency of the response, but there was no corresponding reduction in the amplitude. Depending on the frequency content of the in-service environments, this shift in frequency may or may not be detrimental to the performance of the missile. It was the conclusion of the authors that assuming the vibration and shock conditions produced the failure, the modification would not significantly reduce the failure rates associated with this missile configuration.

## 2.0 REVIEW OF SHIPBOARD TESTING (CGN-40)

The initial task of the program was a review of the test plan [7.2, 7.3] for shipboard testing of the HARPOON in Grade B canisters. The missile system is mounted on a number of classes of ships, and this series of tests was performed aboard the USS Mississippi, a CGN-38 Class ship, during a special at-sea period. The test program was designed to obtain information on the service environments to which the missiles installed in the canisters and on the launch support structures may be subjected. The service environments include constant speed, maneuvering, gunfire and sea states. During the test program, information on the response of the missile to the first three environments was obtained. The objective of the testing and analysis was to determine the potentially damaging environments and to recommend further testing required to determine potential fixes. A reduction of the failure rates of the missiles in the Grade B configuration was the end objective.

An initial review of the data was performed using strip charts of the recorded accelerations. From this preliminary review, it was noted that there was significant dynamic response of the system as a result of 160-rpm excitation. For a five-bladed propeller, this corresponds to a natural frequency of 13.3 Hz (5*160/60). This dominant response was noted at a number of locations on the missile and canister and can be described as an amplified narrow-band random response. Response at all other constant rpm conditions was greatly reduced.

For the thick-walled canister group, the primary response was at 140 rpm or 11.7 Hz. Since this configuration was significantly heavier than the Grade B canister, this reduced frequency was to be expected.

SwRI was supplied by PMTC with a large number of Power Spectral Density plots (PSD's) so that we could determine the nature of the dynamic response of the system. SwRI selected the specific test conditions and accelerometer locations for which analysis was performed. The PSD's for the 160-rpm testing showed elevated response at approximately 5, 13, 25, 37, 60 and 170 Hz. The actual frequencies varied slightly with accelerometer location. We did not attempt to determine the characteristics of the 5-Hz mode because it was felt that the short duration of the test data did not allow for enough averages to provide any confidence in the results at this low frequency. The 13-Hz response was the dominant mode (i.e., had the largest response) for most accelerometer locations. This mode shape was estimated to consist of vertical and transverse bending of both the missile and canister on the launch support structure, with the maximum response at the nose. The important fact was that there was a significant dynamic response of the system at 13 Hz, which may tend to produce failures in the electronics.

The responses at 25, 37 and 60 Hz were approximate multiples of the 13-Hz mode. This indicated that there was significant rattling in the system as a result of the support system utilized. Subsequent testing of the missile indicated that the 170-Hz mode was a local mode of the PC boards.

In general, the PSD data verified the analytical results from the strip charts. There exists a low-frequency (13 Hz) vibration mode which has a significant response amplitude.

## 2.1 Shipboard Testing Conclusions

At the conclusion of this phase of the program, the following results were presented [7.4]:

1) Data analysis was significantly complicated by questionable data. During certain phases of the testing, a number of data channels were clipped or contained significant levels of noise. In addition, the relative amplitude of certain channels was questioned when attempting to define the mode shapes.

2) Missile/canister sets 2, 4, 6 and 8, Grade B canisters, had a coupled launch support structure/canister bending mode at 12 to 14 Hz (i.e., 160 rpm). There was a strong vertical component with smaller lateral and longitudinal motion. All four missile/canister sets behaved in a similar manner.

3) There was significant missile bending inside the canister at this frequency (12 to 14 Hz).

4) The HARPOON Dynamic Simulator (HDS) missile had a strong resonance of a PC board at the same frequency (12 to 14 Hz).

5) All the above responses were strongly excited by both gunfire and 160-rpm shaft vibration.

6) No such dominant mode was identified for the thick-walled canister/missile sets (1 and 3). A lower-level response was evident at 140 rpm.

## 2.2 Shipboard Testing Recommendations

The following recommendations were made concerning areas which SwRI felt should be pursued [7.4]. The object of the sequence of testing given was to develop a system which would provide the required reliability and define procedures whereby modifications to this system could be checked to determine their effect. (Note that the status of work, at the time of preparation of this report, for each one of the areas is given in brackets hereafter, [ ], following each area.)

1) Perform a modal analysis on the missile/canister/launch support structure to verify and further define the major mode shapes. This could be done either in the laboratory or onboard ship, depending on how important deck compliance is. Testing would consist of impact hammer testing to determine the natural frequency, mode shape and damping of the dominant responses of the system. This information would be used to:

   a) Help interpret the field data.

   b) Define potentially damaging responses so that appropriate fixes can be incorporated.

   c) Provide input into test procedures for laboratory testing of the missile/canister system.

   d) Provide input into the development of new qualification test requirements.

   [The mode shapes of the overall system have been defined as described in Section 3.0 and Reference 7.5. It was determined that deck compliance was important in the definition of the low-frequency response of the system. It may be necessary at some later time to go back and define the mass and damping characteristics of the various modes in addition to measuring the response on the missile itself. Measured data was on the launch support structure and the canister only.]

2) Perform laboratory tests on the HDS missile/canister to define missile support problems. The nature of the support of the missile in the canister is a contributing factor to the failure of the missile. The test procedures defined by McDonnell-Douglas provide a good starting point. The modal analysis described above can also provide information as to the nature of the input motion to missile/canister system. The test would be used to:

   a) Study in detail the missile support problem, including the type and locations of the supports.

   b) Define in detail the response characteristics of the missile in the canister so that appropriate fixes can be incorporated.

   [The test at PMTC on the single missile and canister satisfy the majority of the requirements of this recommendation. The test program was oriented to defining relative responses for the various support (studs, shoes and sabots) conditions. Limited information on the response characteristics of the missile and canister were obtained; see Section 4.0 and Reference 7.6.]

3) Perform laboratory tests on the electronic components of the missile, including the Seeker. The major areas where failure has occurred have been in the electronic components near the nose of the missile. It is appropriate to test the forward section of the missile by itself to define potentially damaging responses. The excitation to a system of this size can be more closely controlled than a missile/canister set. The test would be used to define potentially damaging responses so that appropriate fixes can be incorporated. This can include such areas as the Seeker PC board mounting and support.

   [Still open.]

4) Using the information defined in 1), 2) and 3) above, it is possible to recommend fixes for the HARPOON reliability problem. As with any program of this type, it is likely that the fixes will be initially tried during the laboratory testing described above. It is important to consider the extent of the fixes and their cost and how they will affect the reliability of the system. Modifications to the support structure, missile/canister interface, missile support and internal components should be considered. The end product of this phase will be a set of clearly defined modifications to the missile/canister/support structure system which will increase the reliability of the system under service conditions.

   [An a priori selection of a modification was made as to potential modification to the studs and shoes. These modifications were incorporated into the testing at PMTC; see Section 4.0 and Reference 7.6.]

5) Verify the modifications during laboratory tests. If the modifications are simple, this task may be completed during phases 2) and 3). Where major modifications are required, a repeat of some of the laboratory testing may be required.

   [The testing at PMTC indicates that the chosen modifications do not alleviate the dynamic response problems.]

6) Verify the modifications during field testing. A second field testing should be conducted with the type of runs orientated to those which have previously been shown to be important. This test would be used to verify the modifications before they are incorporated into the entire fleet.

   [Still open.]

7) Develop a new vibration and shock test specification reflecting the information obtained above. It is apparent that the original set of test requirements for this system did not adequately define potential weak points in the system. A more realistic

test procedure needs to be developed to ensure that any future modifications to the system will not adversely affect its reliability.

[Still open.]

## 3.0 MODAL ANALYSIS (DD-995)

To answer some of the questions that arose as a result of the USS Mississippi testing, a modal analysis of the missile/canister/launch support structure was performed. This testing was performed on the USS Scott, DD-995, while in port at the Norfolk Naval Base on September 27 and 28, 1984. Data acquisition and analysis was via a four-channel modal analysis system. A total of three simplified analytical models of the missile/canister/launch support structure was developed and data acquired to define their mode shapes. Subsequent analysis of the data at SwRI for modes at 13.1, 18.4, 25.4, 27.5, 31.2, 45.0 and 81.9 Hz verify that there was significant dynamic response of missile/canister/launch support structure.

The analysis of the modal analysis data consisted of plotting the mode shapes for all seven natural frequencies for each of the three models. Reference 7.5 contains the details of the data analysis and results. From all plots of the three different models, it was possible to obtain a general definition of the modes, Table 1. The higher the mode number, the more difficult it becomes to define the system response. More node points would be required to accurately define their response.

TABLE 1. SUMMARY OF MODAL TESTING RESULTS

| Mode No. | Frequency (Hz) | Primary Response Direction | Region of Maximum Response |
|---|---|---|---|
| 1 | 13.13 | Y Side-to-Side | Top of Forward Missile Support |
| 2 | 18.44 | X-Z Fore-Aft and Vertical | Nose of Top Missile |
| 3 | 25.94 | Y Side-to-Side | Rear of Top Missile |
| 4 | 27.50 | X Fore-Aft | Top of Forward Missile Support |
| 5 | 31.25 | Z Vertical | Forward Region of Top Missile |
| 6 | 45.00 | X-Z Fore-Aft and Vertical | Top of Forward Missile Support |
| 7 | 81.88 | Y Side-to-Side | Bottom of Forward Missile Support |

The three side-to-side modes of the system (13.13, 25.44 and 81.88 Hz) did not display any significant cross-axis response. At 13.13 Hz, the primary response was a side-to-side swaying of the system while pivoting about the base. The second side-to-side mode (25.94 Hz) was dominated by motion at the aft end of the system. For this response, the fore and aft portions were out-of-phase. Motion of the third side-to-side mode (81.88 Hz) was extremely complex and could not be simply described. It was possible to compare the 13 and 25 Hz modes with the USS Mississippi testing, and they showed similar response. Comparison of the other modes was not possible.

The other four modes had significant coupling between motion in the vertical and fore-aft directions. In all cases, the three models gave similar results. The 18.44-Hz mode was a heave-type mode with the most significant response at the nose of the top canister. Model No. 3 showed that the lower row of canisters had less motion than the upper row. The 27.50-Hz mode was the first to demonstrate relative motion between the two columns of missile/canisters. For this mode, the fore-aft motion of the two columns was out-of-phase. The higher-order modes are difficult to characterize.

Note that for all the data taken, the modal analysis sytem was in the peak-picking mode. For this condition, the software picks only the amplitude and phase at the defined frequencies and stores that information. It was not possible to determine either the damping or mass characteristics of the system from the results. The results given in this report should only be used to give indications of the mode shapes and not the relative amplitudes. The modal analysis system is capable of producing these values, but the time required to acquire and process the data is significantly higher than the peak-picking process. The testing did provide needed information to verify results from the USS Mississippi testing.

Considering the limited number of accelerometer locations and the fact that no data was taken on the missile, only limited amounts of the data will be useful for input into the laboratory testing at PMTC. Only the highest mode (81.88 Hz) shows any significant bending of the canister itself. All other modes seem to be primarily modes of the entire system, including the launch support structure. None of these will be evident in the testing of only a single missile and canister combination. If the levels of excitation at these lower frequencies are significantly high enough during the laboratory testing, it may be possible to determine their effect on the internal electronic components. It is important to remember that the dynamic problem is affected by both periodic and transient excitation. The periodic excitation is a result of system motion at the natural frequencies. Superimposed on these loads will be those caused by impacting between both the missile to canister and PC board attachments. Since the various components are not rigidly attached to each other, the chance for impacts exists. As the levels of either periodic or transient excitation increase, loss of contact and impacts can occur. These impacts may have a significant effect on the results with respect to failure of components in the missile.

### 3.1 Modal Analysis Conclusions

In general, the modal analysis testing answered a number of questions that arose during the analysis of the data from the USS Mississippi captive carry program. The results indicated the presence of a number of significant modes of the missile/canister/launch support structure. These may have a detrimental effect on the internal missile components, depending on the nature of the transfer of energy from one component to another. Additional modal analysis testing may be necessary, depending on the outcome of tests in progress at PMTC. It may also be necessary to perform additional tests to look at specifically how motion is transmitted from the base of the support structure all the way to local PC cards. Methods to eliminate the path or reduce the levels need to be explored to reduce the number of failures in the missile.

### 3.2 Modal Analysis Recommendations

The following recommendations were made concerning future work on the program in Reference 7.5. (Status of work on these areas is given in brackets.)

1) As a first recommendation, some effort should be placed into a reanalysis of the USS Mississippi data taking into account the results of the modal analysis testing. This may lead to some new insights. (Note that subsequent analysis of laboratory tests of a HARPOON in a canister at Point Mugu have brought to light problems with a large number of the accelerometers used during the USS Mississippi testing. Nonlinearities in output with respect to frequency were noted. These results must be considered when looking back at any data from the USS Mississippi testing.

   [Still open.]

2) For this testing, it was not possible to mount any accelerometers on the missile itself. The system under test was live and the missiles were sealed in the canisters. It may be advisable at some later date to do some additional testing of a system on which accelerometers can be attached directly to the missile itself. During this test, it will also be able to more accurately define the nature of the higher-order modes.

   [Still open.]

3) From the start, it was determined that the relative amplitude, damping and mass characteristics of the various modes were of secondary importance. Because of this and the weather conditions, the modal testing was concentrated on determination of the mode shapes. The intent was to combine these results with those from the USS Mississippi to derive any new requirements for qualification testing. The preliminary results from exploratory tests at PMTC indicated that questions concerning the validity of data taken during the USS Mississippi testing may not allow this to be done. It is possible that the PMTC tests alone will resolve the problem. If not, it may become necessary to do a more detailed and complete modal analysis to determine the amplitude, damping and mass characteristics associated with each mode. Results of this type of testing would have to be interpreted by considering the various mounting locations of the

missiles on different types of ships. Determination of a generic qualification program will take significant effort.

[During the testing at PMTC, the problem associated with the accelerometers used for the USS Mississippi tests were defined. It will be possible, based on available data, to develop a new test specification for the missile electronics. Additional modal analysis work will provide supplemental information to more accurately define the system response for use in the development of the new test specification.]

4) The data presented in this report indicate that the dynamic response of the missile/canister/launch support structure system below 100 Hz is primarily the result of motion of the entire system. The lower modes are dominated by motion of all four canisters on the launch support structure. Both side-to-side and vertical motion of the system are present. A potential solution to the problem of failures in the HARPOON missiles is to reduce the amount of energy input into them. One way of doing this is to modify the design of the launch support structure and its attachment to the ship. Modifications will be directed to increasing the stiffness of the system so that the natural frequency is above those associated with the operation of the ship. It is also advisable to design a mechanism to increase damping of the system. Rather than shifting the natural frequencies, the addition of properly designed damping will reduce the levels of response at the various frequencies. As the levels of energy input into the missile are reduced, the chance of failure is also reduced.

   [Still open.]

5) A second area of study in reducing the energy input into the missile is the missile-to-canister connection. This area is being pursued in the testing active at PMTC. It is important to consider that changes to the system will affect both the natural frequency and damping. Any shift in frequency as a result of a specific fix must be interpreted with respect to the excitation frequencies defined in this report. Shifts downward may be into regions of higher input energy which will adversely affect the performance of the missile. Increases in damping will reduce the level of excitation. When considering the addition of damping materials, they should be added at regions of maximum response so they can effectively work.

   [This work was performed during the testing at PMTC. The testing indicated that the proposed modification provided no significant reduction in the dynamic response of the system.]

6) Solutions may also be in the area of redesign of the PC boards and their attachments in the missile itself. It may not be possible, due to design restraints, to incorporate the changes defined above into the system. If that is the case, it will be necessary to look at the addition of damping materials and

redesign of some internal components of the missile. This area is covered in SwRI's proposal submitted in August of 1984.

[Still open.]

## 4.0 LABORATORY TESTING AT PMTC

The final phase of this program consisted of a review of data obtained during testing at PMTC of the HARPOON Dynamic Simulator (HDS) in a Grade B canister supported by a test fixture. The testing consisted of swept sinusoidal excitation in both the vertical and lateral directions. The majority of the testing was performed in the vertical axis because control problems were encountered for the lateral excitation as a result of vertical lifting of the slip table. The swept sinusoidal excitation was in the frequency range of 5 to 100 Hz with a logarithmic sweep time of six minutes. The excitation level was varied from 0.25 to 2.0 g's peak, as required. In addition to the excitation level, the following parameters were considered in the test sequence:

1) Stud Configuration
2) Shoe Configuration
3) Sabots
4) Mounting Torques
5) Gaps
6) Repeatability

Over 100 separate runs were made to account for the wide variety of parameters considered with a large volume of data produced for each run. Very little detailed analysis of the results of the testing was performed during the test sequence by either PMTC or McDonnell-Douglas. Because of this, some runs were later determined to be unnecessary and additional runs were required to answer specific questions that arose. This included the performance of a random excitation run and the placement of sabots at both the front and rear of the missile.

During the actual testing, some limited data analysis was performed using the HP digital control and analysis system. The majority of the data was subsequently analyzed using this same system. A number of different procedures were used by PMTC to look at the data. These included:

1) Response plots in the excitation frequency range (5-100 Hz)

    a) Unfiltered
    b) Filtered (Tracking, High Pass and Low Pass)

2) Time histories and power spectral density plots at selected peak response frequencies

A huge volume of data was reduced in this manner. It was not possible to look at each run in detail. The approach taken was to determine the trends of the data with respect to the effect of the various modifications and test conditions. For the more detailed analysis, some of the parameters, such as excitation level, were ignored. In the final analysis, no more than ten of the original 100 runs were analyzed in detail.

In addition, SwRI performed some additonal analysis of the data to determine the high-frequency response (100 to 500 Hz) of the system to the input excitation in the range of 5 to 100 Hz. These were in the form of peak hold PSD's from 5 to 500 Hz. In the excitation frequency range, these corresponded to the tracking filtered data obtained by PMTC. In the high-frequency range, they showed the peak response of the system during the entire sweep, not just the selected frequencies described above. For this type of data analysis, only limited runs and locations were considered. Individual PSD's and the corresponding transfer functions were obtained.

The final phase of data analysis that SwRI was involved in was a determination of the phase relationship among the responses at various locations along the missile and canister. This was an attempt to obtain an indication of the mode shape of the response. The random excitation run, with sabots front and rear, was utilized for this analysis which was performed using a modal analysis system. Some problems were encountered because of differences in the recording procedure for the missile accelerometers and the canister and support structure accelerometers. There was a varying phase shift between the two types of accelerometers which did not allow full utilization of the modal analysis system. Details of the results of this data analysis is contained in Reference 7.6 and are summarized herein.

## 4.1 Laboratory Testing Conclusions

In general, the missile/canister system is not rigid in the 5 to 100 Hz frequency range. All configurations displayed significant resonances associated with bending of the entire test setup as well as localized responses of the missile in the canister. Due to size and weight of the test item, it was not possible to develop a test fixture which was rigid in the entire frequency range, and its response to the input had to be taken into account in any reduction of the data.

Vibration had the tendency to affect the torque in the mating of the canister to the missile. Depending on the location, the torques either increased or decreased. These changes had a minor effect on the dynamic response of the missile in the canister. Because of the limited data available, it was not possible to define the local response in any detail. It was noted that the adjustment screws did not turn, and the shifts were the result of shifting of the missile within the canister. Torque retention was improved with the modified studs. Note that this may not be the case when the studs are aerodynamically designed.

A gap was introduced in the separation bolt interface at the rear of the missile as a result of the vibration. This gap may allow the missile to move axially within the canister.

Repeatability of successive tests was good. If the specified torques were adjusted between runs, the results are similar. There were some minor shifts in the amplitude and frequencies of the response as a result of this type of testing. Secondly, if the torques were not adjusted between runs, there was only minor changes in the dynamic response of the system for the case of the modified hardware and vertical excitation. The shifts in torque did not seem to have any effect on the overall dynamic response of the system. This did not seem to be the case for lateral excitation. Data for the lateral response was not presented because of problems with the slip table encountered during testing.

The following conclusions were drawn with respect to the several configurations tested.

### 4.1.1 Production Hardware

As a result of the metal-to-metal contact at both the shoes and the studs, there was significant rattling of the missile in the canister. The rattling tended to have an effect on the vibration of the local PC boards due to its energy content in the high-frequency region. This rattling was aggravated by gaps at the studs. There was significant dynamic response of the system within the test frequency, less than 100 Hz. For this configuration, the peak response occurred at approximately 73 Hz.

### 4.1.2 Modified Shoes with Production Studs

For all the locations considered, this configuration can be considered similar to the production hardware configuration. There was no significant shift in the primary response frequency or the content of the high-frequency response.

### 4.1.3 Production Hardware with Sabots

There were only minor variations in this configuration when compared to the original hardware configuration. The level of the primary response was the same with only a slight increase in the natural frequency. There was some decrease in the peaks of the high-frequency response, but the energy has been broadened out into a wider-frequency range. The net results of these changes cannot be determined.

### 4.1.4 Modified Shoes and Studs

This configuration did soften the system with a resulting shift in the primary response to approximately 35 Hz. The level of this response was not significantly changed. Rattling still occurred with some minor shifts in frequency and amplitude. Without the performance of combined reliability and functionality testing, the effect of the changes cannot be defined exactly. Indications were that the changes are not significant enough to justiy a modification based soley on this series of testing.

### 4.1.5 Production Shoes with Modified Studs

The results for this configuration were similar to those of the completely modified system. This indicates that for vertical excitation only, modifications to the studs were effective. The general conclusions drawn for the fully modified system also apply here.

## 4.2 Laboratory Testing Recommendations

In Reference 7.6, the following recommendations were made. (Where applicable, the status of additional work in these areas is noted in brackets.)

1) For excitation in the vertical direction, the modified shoes show only minor effects. Unless it can be demonstrated that they are effective for horizontal excitation, they should not be considered.

2) The use of sabots does not significantly reduce the level of vibration seen at the Seeker and FCE ring. Without further study, their inclusion in any potential modification is not justified.

3) The modified studs do affect the primary natural frequency of the system. This frequency is shifted from approximately 73 to 34 Hz. There is no significant decrease in the level of either the primary mode or any of the higher-frequency response of the system. If a decision is made to modify the studs in any way, some additional testing of the aerodynamic modifications will be required prior to inclusion in the fleet as a whole.

4) Any proposed modifications must also take into account the shock requirements of the system. It may not be possible to design a modified stud which will effectively reduce the vibration levels and at the same time be effective in the shock environment. Additional analysis and/or testing needs to be performed in this area.

5) Modifications to other portions of the system should be considered in terms of their effectiveness and cost. As noted earlier, one potential area of consideration is modifications to either the internal electronic components or their mounting in the Seeker. The addition of damping to the PC boards has the potential of reducing the levels significantly. Consideration of modification of the canister to the Launch Support Structure (LSS), the LSS structure itself and the LSS structure to deck interface. In all cases, the objective should be to add damping to the system and not significantly change their dynamic charactersitics.

   [Still open.]

6) Some additional work needs to be done in the area of determining what influences the dynamics of the shipboard motion will have on the modified system. It is extremely important to insure that the modifications do not shift the frequency of the system into the range of excitation on the ship. Some additional analysis of the USS Mississippi data will be required to do this.

   [Still open.]

7) In conjunction with recommendation 6), a determination of the adequacy of the current qualification program needs to be made. If necessary, this may include the development of an entirely new specification.

[Still open.]

## 5.0 RESULTS AND CONCLUSIONS

The original proposal [7.1] contained a total of seven tasks including:

Task 1 - Initial Review

Task 2 - Preliminary Scan of the Data

Task 3 - Develop an Operational Profile

Task 4 - Digitize Selected Data

Task 5 - Compute PSD's of all Selected Data

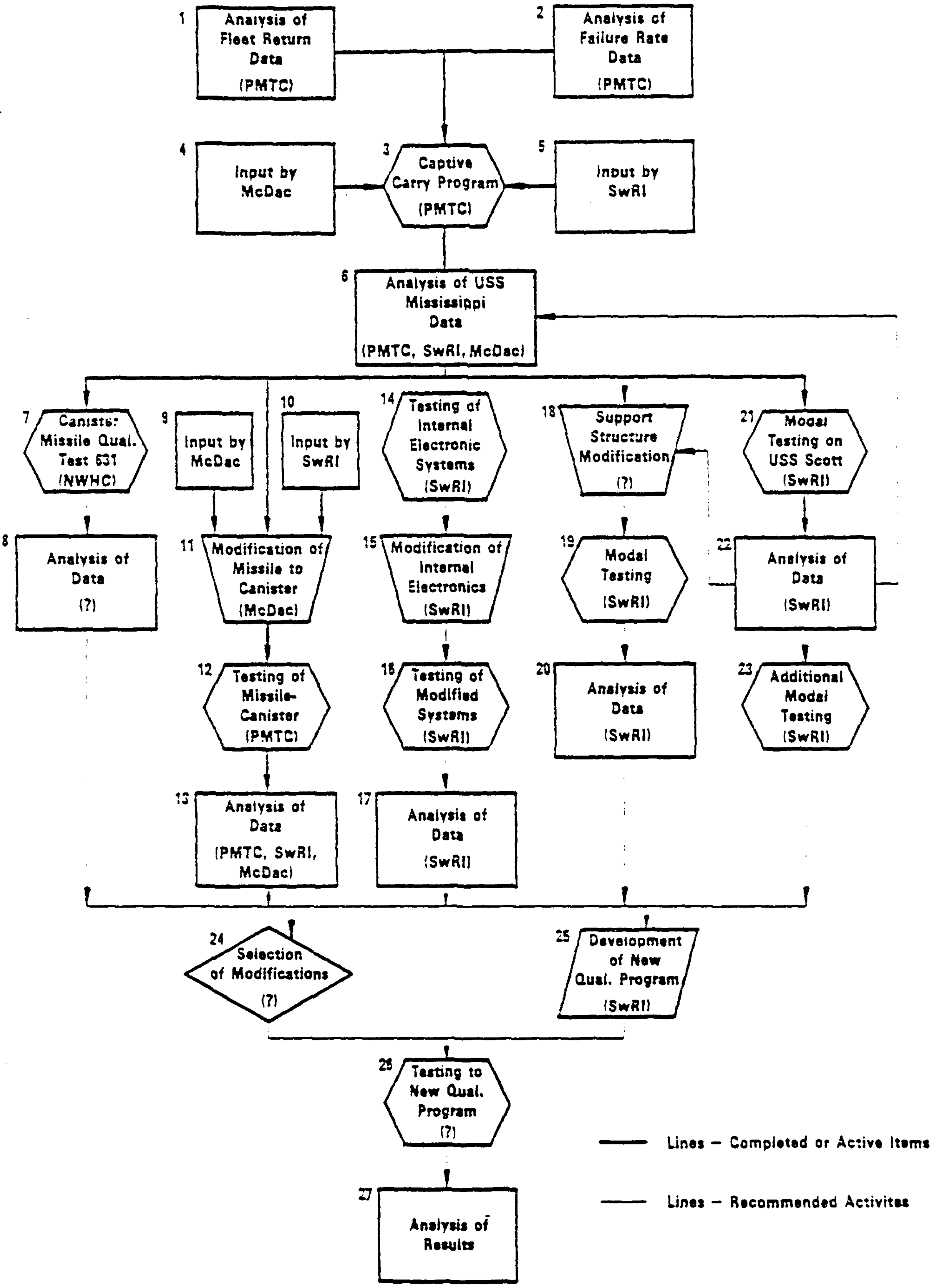
Task 6 - Develop a Real Time Composite PSD Test Specification

Task 7 - Develop an Accelerated Test Specification

All these tasks were originally associated with the the USS Mississippi testing only. Subsequent to the initiation of the program and under the direction of PMTC personnel, the scope of work has changed significantly. Of the original seven tasks, results have previously been presented for Tasks 1, 2, 4 and 5 [7.4]. The emphasis of the program shifted from the development of a test specification to support of PMTC in the analysis of the test data produced at PMTC. The results of this analysis are presented in this and previous reports.

An overview of the entire HARPOON missile program, as viewed by SwRI, in association with dynamic reliability was summarized in Reference 7.7. The attached flow chart gives SwRI's understanding of the interrelationship between the various phases of the program for which SwRI has provided some input. Additional areas, of which SwRI has not been directly involved, are not included. Note also that for a program of this complexity, the scope of work can shift as additional data become available. This is reflected by the change for the initial tasks defined in Reference 7.1 and those that SwRI sees as most important at the present time.

Steps 1 and 2 in the attached flow chart indicate that the HARPOON in the Grade B canister had failure rates significantly higher than other configurations. Because of this, the Navy initiated a program to determine the environmental condition causing this increased failure rate. The first testing consisted of the captive carry program aboard the USS Mississippi (Step 3). Limited input into this task was provided by SwRI with the majority of information coming from the Naval Ship Weapon Systems' Engineering Station (NSWSES) and the Pacific Missile Test Center (PMTC). SwRI's review is summarized in Reference 7.4. At that time, SwRI felt that the performance of some preliminary tests would ensure that the full-scale captive carry program would




Flow Chart of HARPOON Grade B Canister Test Program provide useful information. Decisions were made to proceed with the original plan.

SwRI's analysis of the captive carry testing, Step 6, indicated the presence of significant dynamic response of the missile/canister/launch support structure system. These responses were excited by both the normal operation of the ship and the gunfire. This response was noted from both the time history and the PSD data obtained from PMTC. Results from this step were given in Reference 7.4. Subsequent data for the testing at PMTC (Steps 12 and 13) and the modal analysis testing (Steps 21 and 22) indicated that a review of the findings might be appropriate, Reference 7.6. Because of the significant dynamic response of the system, additional testing was initiated.

The first set of tests performed was that done at NWHC (Step 7) on the canister itself. At the present time, only preliminary results of this test have been looked at by SwRI (Step 8). They tend to verify the information obtained during the testing at PMTC.

A second type of testing (Steps 21 to 22) consisted of modal analysis testing of the missile/canister/launch support structure on the USS Scott. The testing was designed to define the natural frequencies and associated mode shapes of the system below 100 Hz. Results indicated significant response at frequencies similar to those seen during the USS Mississippi testing. These results are summarized in Reference 7.5.

The third type of testing (Steps 9 to 13) consisted of the testing of a single missile/canister under horizontal and vertical excitation. The primary input as to modifications to the missile-to-canister interface was supplied by McDonnell-Douglas with SwRI input in the area of testing to be performed. As with the captive carry program, the initial test plan was adhered to. A number of probems were noted during the test program, including (Reference 7.6):

1) Nonlinearities in some of the accelerometers on the HDS. Only a limited number of these accelerometers are useful.

2) Scaling problems in display of the acceleration results. Careful attention needs to be payed to this in any analysis carried out.

3) Failure of the rails in the canisters due to previous testing.

4) Flexure of the test fixture which may influence interpretation of the results if this is not taken into account. This includes interaction between the fixture and test item.

Preliminary analysis of the data obtained from the test at PMTC indicated that the modifications made do shift the frequency of the primary response of the missile in the expected direction. Whether these shifts will reduce the rate of failures depends on their relationship to the resulting internal response of the electronics and the nature of the field environments. If the shifts are into regions of higher input energy, the modifications will be counterproductive. Indications are that the levels of response are not reduced by the modifications. One unquestionable result is that the inclusion of gaps has a detrimental effect on the response. Any design modification should be aimed at eliminating gaps under both vibration and shock excitation.

## 6.0 RECOMMENDATIONS

As the program progressed, the requirements of the program shifted from those given in Reference 7.1. A second proposal, Reference 7.8, outlined several additional areas of work. The first was to go back and look at Steps 1 and 2 again to get a better idea of the location and nature of failures that have been noted. This would be aimed at determining the location of most failures and defining the environmental condition causing the failures. Also recommended was to perform some testing on the internal electronic systems alone. One potential area of modification is in the area of added damping and support structure changes to the PC boards. It may not be possible to reduce the levels of input otherwise, so this may become necessary. Before modifications are made, tests of current systems should be performed to define the environment. After this, any modifications can be made in regions which will do the most good. Additional tests will then be performed to check out the changes made in the system.

As a result of the modal analysis test, it was noted that the majority of low-frequency response was associated with the launch support structure itself. It was recommended that modifications, either stiffening or adding damping, to the system be considered (Step 18). Testing and subsequent analysis of the results (Steps 19 and 20) would indicate the effectiveness of these changes.

Additional modal analysis testing was also recommended as a result of Steps 13 and 22. Indications are that a number of the accelerometers used in the USS Mississippi testing were questionable. Therefore, they cannot be utilized in the development of a new qualification test program (Step 25). To accurately define the dynamic characteristics of the system, some additional modal tests were recommended in Reference 7.5 as input into the qualification test procedure. In addition, it was recommended to go back and look at the USS Mississippi data using this information.

The end products of the program seem to be the selection of modifications to reduce failures (Step 24) and the development of a new qualification test program more representative of the service and transportation environments (Step 25). Performance of the new qualification tests on both an original and modified missile/canister set will be informative. Note that more recent failure analysis data had indicated that the newer missiles that have been installed in the fleet have an improved failure rate when compared to the original group. The information obtained from this work has been informative, but no modifications may be required.

The requirements for the development of a vibration and shock qualification program have been looked at in some detail. This work can be divided into four areas as defined below.

### 6.1 Development of an Operational Test Profile

This corresponds to Task 3 of the original proposal, Reference 7.1. The purpose is to define a set of operating conditions and times that the item would be subjected to these conditions. This requires a definition of the history of a typical system. The types of environments to be considered should include:

| Environment | Conditions |
|---|---|
| Transportation from production facility to storage or ship | Shock & Vibration |
| Logistic transport: dock to ship, ship to ship, storage to dock, etc. | Shock & Vibration |
| Operational profile | |
| Ship Motion | |
| Propeller excitation | Vibration |
| Maneuvering | Vibration |
| Sea states | Shock & Vibration |
| Armaments | |
| Gunfire | Shock |
| Nuclear Blast | Shock |

6.2 Development of Real Time Vibration and Shock Environments

This corresponds to Task 6 of the original proposal, Reference 7.1. The available data on the environments defined above would be combined into a number of composite levels which reflect the type, level and duration of the exposure. Specified vibration levels would be in the form of either sinusoidal levels and frequencies or random PSD's, depending on the nature of the excitation. The shock can be considered repetitive shock with a shock spectrum used to define the levels. From the initial review of the USS Mississippi testing, it may not be possible to calculate the shock response data due to clipping of the signals. It may be necessary to rely on data available in the literature for this information.

6.3 Development of an Accelerated Shock and Vibration Specification

This correponds to Task 7 of the original proposal, Reference 7.1. For the vibration environments, it will be necessary to accelerate the testing to demonstrate functionality of the systems. By increasing the amplitudes, the time can be reduced in accordance with engineering practice. It is not possible to scale the shock excitation, so the test will incorporate a number of repetitive shocks. Tests will be similar to MIL-STD-901 requirements.

6.4 Comparison of Results to Current Requirements

This is a new task that appears to be necessary to answer some questions about the reasons for the currently high failure rates. The current vibration requirements are given in Figure 6.1. The real time and accelerated vibration PSD's should be compared to the current requirements with respect to both amplitude and duration. The developed shock requirements should also be compared to the expected field shock levels.

Due to the rapidly changing scope of work of this program, it was not possible to complete all the tasks defined in the original proposal as

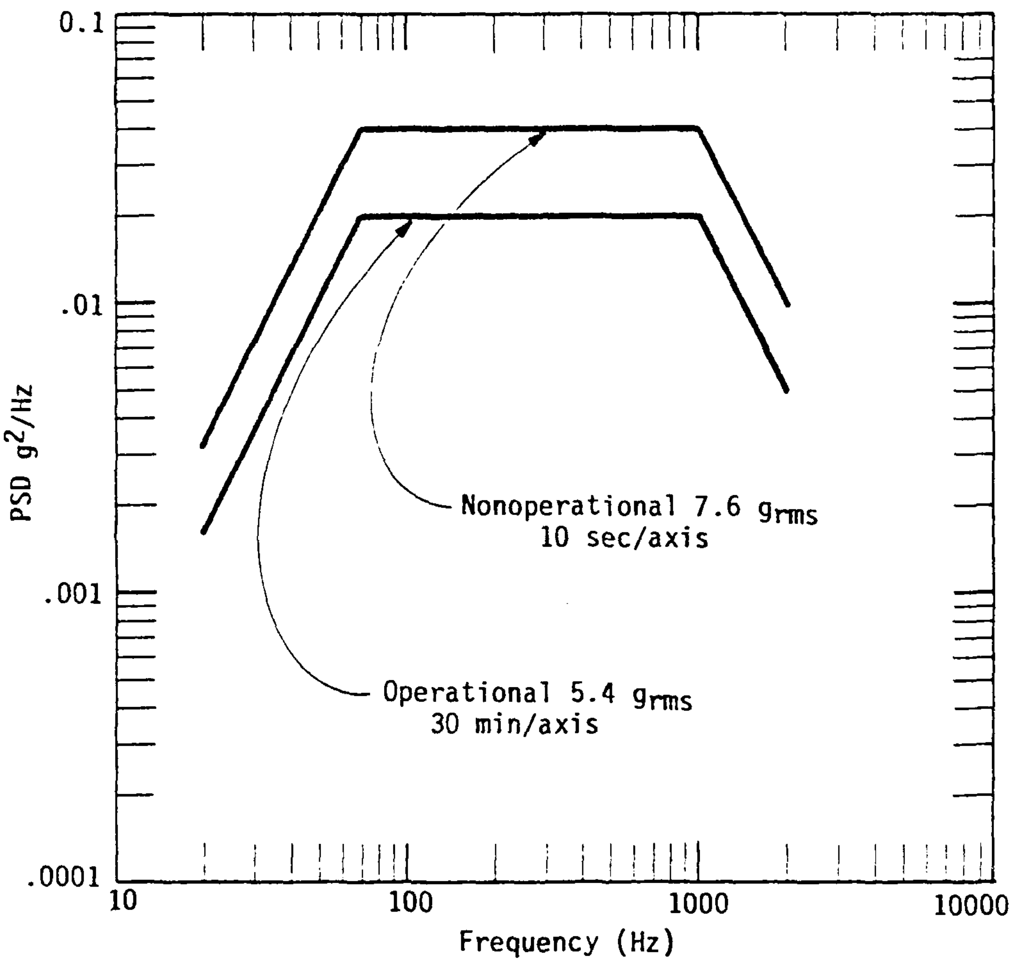



Figure 6.1 HARPOON Seeker Design Verification Random Vibration Test Spectrums

(McDonnell Douglas Data)

described above. Under the direction of PMTC personnel, the work evolved to that described in this report. It is still felt that some areas defined in the original proposal and those given above should be pursued.

## 7.0 REFERENCES


7.1 "Pre-proposal Scope and Cost Estimate to Develop Accelerated Test Specification For Grade B Canister Configuration," SwRI Leter to Mr. Bergen, 21 July 1983.

7.2 "Canisterized HARPOON Failure Investigation Test Plan, Preliminary," Naval Ship Weapon System Engineering Station, 25 June 1983.

7.3 "CGN-40 HARPOON Canister Shipboard Environmental Measurement Test Plan," Pacific Missile Test Center, February 1984.

7.4 "Status Report on CGN-40 HARPOON Canister Shipboard Test Data Analysis," SwRI Report, SwRI Project 15-5607-826, June 1984.

7.5 "Status Report on DD-995 HARPOON Shipboard Modal Analysis," SwRI Report 15-5607-826, February 1985.

7.6 "Status Report on HARPOON Canister Laboratory Test Data Analysis," SwRI Report 15-5607-826, July 1985.

7.7 "Development of Accelerated NDT Specifications for Grade B Canister," SwRI Status Letter to Mr. Ribiat, 8 February 1985.

7.8 SwRI Proposal 06-0478A, "Development of Accelerated NDT Specification for Grade B Canister Configuration," to Mr. Gary Ribiat of PMTC, August 1984.

END
DATE
FILMED
9-88
DTIC